

NARCISTATIN PRODRUGS

RELATED APPLICATION DATA

This application is based on and claims the benefit of U.S. Provisional Patent Application No. 60/432,219 filed on December 9, 2002.

INTRODUCTION

Financial assistance for this invention was provided by the United States Government, Division of Cancer Treatment and Diagnosis, National Cancer Institute, Department of Health and Human Services, Outstanding Investigator Grant CA44344-03-12 and CA90441-01; the Arizona Disease Control Research Commission; and private contributions. Thus, the United States Government has certain rights in this invention.

FIELD OF THE INVENTION

This invention relates to a novel compounds, and methods for synthesizing same, which show promising utility in the treatment of cancer. The compound described herein has been denominated narcistatin. Further described herein are numerous derivatives of narcistatin.

BACKGROUND OF THE INVENTION

Over 30 species representing 11 genera (among 85 total) of the plant family Amaryllidaceae have been employed in traditional treatments for human cancer. Such applications of certain *Narcissus* species were recorded as early as 200 B.C. (Pettit, G. R. *et al.*, *J. Nat. Prod.* 1995, 58, 756-759; Pettit, G. R., *et al.*, *J. Nat. Prod.*, 1995, 58, 37-43.) The biologically active constituents of Amaryllidaceae species have been under investigation from at least 1877 following Gerrard's report on a component of *Narcissus pseudonarcissus* designated narcissia. (Gerrard, A. W., *Pharm. J.*, 1877, 8, 214; Cook, J. W., In *The Alkaloids*, Manske, R. H. F.; Holmes, H. L., Ed.; Academic Press: New York, 1952; pp. 331.) Presently, some 48 alkaloids and carbostyrils bearing a variety of carbon skeletons have been isolated

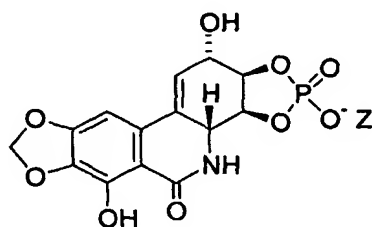
from *Narcissus* species. (Weniger, B., *et al.*, *Planta Med.*, 1995, 61, 77-79.) Of these, the isocarbostryls narciclasine (1) and pancratistatin (2) have been found to display the most promising *in vivo* antineoplastic activities and a selection of other amaryllidaceae alkaloids have been shown to provide cancer cell growth inhibitory activity. (Pettit, G. R., *et al.*, *J. Nat. Prod.*, 1995, 58, 756-759; Pettit, G. R., *et al.*, *J. Nat. Prod.*, 1995, 58, 37-43; Pettit, G. R., *et al.*, *J. Org. Chem.*, 2001, 66, 2583-2587; Rigby, J. H., *et al.*, *J. Amer. Chem. Soc.*, 2000, 122, 6624-6628; Suffness, M., *et al.*, In *The Alkaloids*, Drossi, A., Ed., Academic Press: New York, 1985; pp. 205-207; Youssef, D. T. A., *et al.*, *Pharmazie* 2001, 56, 818-822.)

Pancratistatin (2), which we first discovered in *Pancratium littorale* (reidentified as *Hymenocallis littoralis*) and later in *Narcissus* species, has been undergoing extended preclinical development. (Pettit, G. R., *et al.*, *J. Org. Chem.*, 2001, 66, 2583-2587; Rigby, J. H., *et al.*, *J. Amer. Chem. Soc.* 2000, 122, 6624-6628; Pettit, G. R., *et al.*, *J. Nat. Prod.*, 1995, 58, 756-759; Pettit, G. R., *et al.*, *J. Nat. Prod.*, 1995, 58, 37-43.) That very important initiative was greatly assisted by conversion of the sparingly soluble isocarbostryl to a 7-O-phosphate salt. (Pettit, G. R., *et al.*, *Anti-Cancer Drug Design* 2000, 15, 389-395; Pettit, G. R., *et al.*, *Anti-Cancer Drug Design* 1995, 10, 243-250.) The antimitotic activity of narciclasine (1) has been known for over 35 years. Subsequently, it was shown in U.S. National Cancer Institute research to be active against *in vivo* growth of the M5076 sarcoma and P388 lymphocytic leukemia. In addition, it was found to inhibit protein synthesis in Erlich asciter cancer cells. (Suffness, M., *et al.*, *The Alkaloids*, Drossi, A., Ed., Academic Press: New York, 1985; pp. 205-207.) However, as with the closely related pancratistatin (2), the low solubility properties of narciclasine has contributed to the delay in its preclinical development. Most of the inventors' early investigation involving this potentially useful isocarbostryl have targeted its use as a starting point for a practical synthesis of pancratistatin

(2) and for SAR purposes. (Pettit, G. R., *et al.*, *J. Org. Chem.* 2001, 66, 2583-2587; Rigby, J. H., *et al.*, *Amer. Chem. Soc.* 2000, 122, 6624-6628; Pettit, G. R., *et al.*, *J-C. Heterocycles* 2002, 56, 139-155.) Disclosed herein a very convenient transformation of narciclasine (1) to water soluble cyclic phosphate prodrugs (3).

SUMMARY OF THE INVENTION

Disclosed herein are several derivatives of narciclasine, and methods for the synthesis of these derivatives. The compounds of the invention have the following structure:



Compound 3a:	Z = pyridinium
Compound 3b:	Z = H ⁺
Compound 3c:	Z = Li ⁺
Compound 3d:	Z = Na ⁺
Compound 3e:	Z = K ⁺
Compound 3f:	Z = Cs ⁺
Compound 3g:	Z = Mg ²⁺
Compound 3h:	Z = Ca ²⁺
Compound 3i:	Z = Zn ²⁺
Compound 3j:	Z = Mn ²⁺
Compound 3k,	Z = quinidine
Compound 3l:	Z = quinine
Compound 3m:	Z = imidazole
Compound 3n:	Z = morpholine
Compound 3o:	Z = piperazine

Narcistatin (3b) and fifteen salt derivatives were evaluated against a panel of human cancer cell lines and the range (0.1 - 0.01) of GI₅₀ values in µg/ml was found to parallel that shown by the parent narciclasine, and thus indicates that the compounds of the present invention show promise in the treatment of cancer in humans and animals. The water-soluble cyclic phosphate prodrugs disclosed herein will allow the potentially useful *Narcissus*

anticancer component narciclasine to be utilized in cancer-fighting pharmaceuticals.

Also disclosed herein is a method for the efficient synthetic conversion of the sparingly soluble anticancer compound isocarbostyryl narciclasine (1), a component of various *Narcissus* species, to a more soluble cyclic-phosphate designated narcistatin (3b). The reaction between narciclasine, tetrabutylammonium dihydrogen phosphate, dicyclohexylcarbodiimide, and *p*-toluenesulfonic acid in pyridine afforded pyridinium narcistatin (3a) in reasonable yields. Preparation of sodium narcistatin (3d) was achieved by two methods. Procedure A involved the transformation of narcistatin (3a) into the water soluble prodrug (3d) and other salt derivatives by cation exchange chromatography. Procedure B allowed sodium narcistatin (3d) to be obtained in high yield, following cation exchange chromatography, from the reaction between narciclasine, tetrabutylammonium dihydrogen phosphate and dicyclohexylcarbodiimide in pyridine.

DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates the x-ray structure of pyridinium narcistatin (3a).

Figure 2 illustrates the x-ray cell contents of pyridinium narcistatin hydrate (3a).

Figure 3 illustrates the chemical structure of the narcistatin cyclic phosphate compounds of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Early experience by one of the inventors in nucleotide chemistry involving phosphate esters and cellular phosphatases combined with recent successes in synthesis of phosphate prodrugs made such an approach most attractive for obtaining a water soluble narciclasine prodrug. (Pettit, G. R. *Synthetic Nucleotides*, Van Nostrand Reinhold Co: New York, 1972; Pettit, G. R., *et al.*, *Anti-Cancer Drug Design* 2000, 15, 389-395; Pettit, G. R., *et al.*, *Anti-Cancer Drug Design* 1995, 10, 243-250; Pettit, G. R., *et al.*, *Anti-Cancer Drug Design* 2000,

15, 397-403; Saulnier, M. G., *et al.*, Med. Chem. Lett. 1994, 4, 2567-2572; Ueda, Y., *et al.*, Med. Chem. Lett. 1995, 5, 247-252.) However, a selection of the more obvious methods such as POCl₃, or 2-cyanoethylphosphate with dicyclohexylcarbodiimide (DCCI), and various unprotected or protection (e.g. narciclasine 3,4-acetonide) strategies involving narciclasine (1) led to unpromising mixtures. (Pettit, G. R., *et al.*, Anti-Cancer Drug Design 2000, 15, 389-395; Pettit, G. R., *et al.*, Anti-Cancer Drug Design 1995, 10, 243-250; Taktakishvili, M., *et al.*, Tetrahedron Lett. 2000, 41, 7173-7176; Tener, G. M., J. Amer. Chem. Soc. 1961, 83, 159-168; Scheit, K. H., Nucleotide Analogs, Synthesis and Biological Function; Wiley-Interscience: New York, 1972; Khorana, H. G., *et al.*, J. Chem. Soc. 1953, 2257-2260; Khorana, H. G. J. Amer. Chem. Soc. 1954, 76, 3517-3527; Dekker, C. A., *et al.*, J. Amer. Chem. Soc. 1954, 76, 3522-3527; Tener, G. M.; Khorana, H. G., J. Amer. Chem. Soc. 1955, 77, 5348.) Eventually, the inventors examined use of the readily soluble tetrabutylammonium dihydrogen phosphate in pyridine as the phosphate source. Initially, the phosphate failed to couple with narciclasine in the presence of DCCI until three equivalents of *p*-toluenesulfonic acid was employed to promote condensation, at which point precipitation of dicyclohexylurea (DCU) began. When the reaction mixture was heated to 80°C, the pyridinium salt of narciclasine-3,4-cyclic phosphate 3a (herein designated pyridinium narcistatin), precipitated. Following collection of precipitated DCU and the narcistatin pyridinium salt, the solids were titrated with water to dissolve the cyclic phosphate (3a). Concentration of the water fraction afforded the pyridinium salt in 40% yield. The mother liquor was concentrated to a brown oil and added to a large volume of water; an immediate precipitate was observed. The solution was filtered and the filtrate was found to be primarily unreacted narciclasine with some DCU as impurity. The reaction did not go to completion even after prolonged stirring and addition of more reagents.

Examination of the ^1H -NMR (DMSO-d_6) spectrum of the pyridinium salt **3a** showed a multiplet corresponding to the signals for four protons at 4.42–4.31 ppm and a doublet of doublets corresponding to the signal for one proton at 4.15 ppm. Assuming four ring hydrogens resonating in this region, the signal for H-1 was assigned downfield at 6.5 ppm. Only one of the signals corresponded to a hydroxyl group. A D_2O experiment resulted in a considerable change in the splitting pattern of the multiplet at 4.3 ppm and 8.60 ppm, suggesting loss of the OH signal and NH-5 signal, respectively. Other signals at 13.66 and 9.00 were also absent from the D_2O treated spectrum due to deuterium exchange with OH-7 and pyridinium NH. The ^{31}P -NMR (DMSO-d_6) spectrum gave one signal at 20.3 ppm suggesting only one phosphorus atom, this together with the ^1H NMR data suggested the formation of the cyclic phosphate. However, despite extensive 2D NMR experiments, the position of the phosphate could not be established unambiguously. Consequently, narciclasine pyridinium salt (**3a**) was recrystallized from pyridine-water and examined by X-ray crystallography to establish the 3,4-cyclic phosphate structure. The resulting structure of **3a** is depicted in Figure 1. In addition to two pyridinium cations and two cyclic phosphate anions, the unit cell was found to contain three molecules of water solvate, as shown in Figure 2.

In order to extend the narcistatin cation series, phosphoric acid **3b** was prepared by dissolving the pyridinium narcistatin in water and passing it through a column containing Dowex 50W X8 200 cation exchange resin (hydrogen form). A solution of the pyridinium narcistatin in water was also used to prepare the lithium (**3c**), sodium (**3d**) (procedure A), potassium (**3e**) and cesium (**3f**) salts of narcistatin by passage through a Dowex 50W X2 column bearing the respective cations. The magnesium (**3g**), calcium (**3h**), zinc (**3i**), and manganese (**3j**) salts were obtained by suspending phosphoric acid **3b** in methanol-water

(3:2) and adding 0.5 equivalent of the respective metal acetate in water. The resulting opaque solution was stirred for several days as the salt precipitated from solution. These dication salts proved to be only sparingly soluble in water. A selection of ammonium salts were prepared by allowing phosphoric acid **3b** to react with the respective amine (1.2 equiv) at room temperature. The reaction mixture was concentrated and product precipitated to give ammonium salts **3k-o**. Procedure B for the preparation of sodium narcistatin **3d** is as follows. The reaction between narciclasine, tetrabutylammonium dihydrogen phosphate and DCCI in pyridine was carried out at 80°C without the addition of the para-toluene sulfonic acid. The reaction was monitored by ¹H NMR and found to go to completion in four days with addition of more reagents at 24 hours. Isolation followed by cation exchange chromatography gave sodium narcistatin in high yield (88%).

Narciclasine cyclic phosphate prodrugs **3a-o** were evaluated against a minipanel of human cancer cell lines and the murine P388 lymphocytic leukemia. Results of the cancer cell line evaluation of narcistatins **3a-o** appears in Table 1. The GI₅₀ 0.1-0.02 µg/ml strong activity range parallels that already reported for the parent, narciclasine (**1**). (Pettit, G. R.; Melody, N.; Herald, D. L. J. Org. Chem. 2001, 66, 2583-2587.)

Experimental Section.

Narciclasine (**1**) was isolated from *Hymenocallis littoralis* (Jacq.) Salisb, (Amaryllidaceae) grown by our group in Tempe, Arizona. (Pettit, G. R., *et al.*, J. Nat. Prod. 1995, 58, 756-759; Pettit, G. R., *et al.*, J. Nat. Prod. 1995, 58, 37-43.) Reagents were purchased from Aldrich Chemical unless otherwise noted and used as received. Solvents were distilled prior to use and pyridine preceding distillation was dried over potassium hydroxide pellets. Dowex 50X8-200 and Dowex 50WX2 cation exchange resins (H⁺ form) were washed with methanol, 1 N hydrochloric acid and deionized water. The cation forms of

the resin were obtained by washing with a 1 *N* solution of the appropriate base followed by deionized water. DEAE SEPHADEX A-25 weak anion exchange resin (acetate form) was purchased from the Sigma-Aldrich Company and was washed with 1 *N* triethylammonium bicarbonate (TEAB) solution and then equilibrated with 10 mM TEAB buffer solution.

Melting points were determined on a Fisher-Johns melting point apparatus and are uncorrected. Thin layer chromatography was performed on Analtech silica gel GHLF plates, the narciclasine containing derivatives were visible as green-blue fluorescent spots under long wave ultraviolet light, and were rendered permanent by staining with iodine vapor. Phosphorous containing compounds were detected using the modified Jungnickel's reagent (perchloric acid - malachite green - sodium molybdate) developed by Vaskovsky and Latshev. (Khorana, H. G., *et al.*, A. R. J. Chem. Soc. 1953, 2257-2260; Khorana, H. G., J. Amer. Chem. Soc. 1954, 76, 3517-3527; Dekker, C. A., *et al.*, H. G. J. Amer. Chem. Soc. 1954, 76, 3522-3527; Tener, G. M., *et al.*, J. Amer. Chem. Soc. 1955, 77, 5348.) Optical rotation values were recorded using a Perkin Elmer 241 polarimeter. High resolution FAB spectra were obtained using a JEOL LCMate magnetic sector instrument in either the FAB mode, with a glycerol matrix, or by APCI with a polyethylene glycol reference. All ¹H NMR spectra were obtained using a Varian Gemini 300 MHz instrument unless otherwise noted. The ¹³C, ¹H-¹H COSY, ¹H-¹³C HMBC, ¹H-¹³C HMQC, and ³¹P-NMR experiments were conducted employing a Varian Unity 500 MHz instrument.

Pyridinium Narcistatin (3a)

Narciclasine 1 (1.0 g, 3.4 mmol) was added to pyridine (50 ml) and the solution was heated to 80°C. Next, tetrabutylammonium-dihydrogen phosphate (5.13 g, 15.11 mmol, 4.4 equiv), dicyclohexylcarbodiimide (5.0, 24.5 mmol, 7.0 equiv) and *p*-toluenesulfonic acid (3.0 g, 15.8 mmol, 4.63 equiv, added slowly) were added. After 2g of the sulfonic acid was

added, a precipitate began to separate. The reaction mixture was stirred under argon at 80°C for 2.5 hours. The precipitate was collected and washed with methanol to remove pyridine. The precipitated cyclic phosphate (3a) was separated from the DCU by washing with water (200 ml). The aqueous filtrate was concentrated to an off-white solid and dried (vacuum) overnight to yield 0.59 g, 40.4%. The mother liquor was concentrated to a brown oil and water (750 ml) added. An immediate precipitate was observed, which was collected and dried to 0.75 g of white solid. The ^1H NMR (DMSO- d_6) showed this material to be recovered starting material with a small amount of DCU impurity. Recrystallization of phosphate 3a from pyridine-water gave crystals that were used for X-ray crystallography. $[\alpha]_D^{26} = -6.4^\circ$ (c 0.44, DMSO); m.p. 275°C; ^1H NMR (DMSO - d_6 , 500 MHz) δ 13.66 (s, 1H), 9.00 (s, 1H), 8.60 ppm (m, 3H), 7.9 (t, $J = 7.5$ Hz, 1H), 7.5 (m, 2H), 7.04 (s, 1H), 6.5 (s, 1H), 6.06 (d, $J = 3$ Hz, 2H), 4.42-4.31 (m, 4H), 4.15 (dd, J_{14} , 6.5 Hz, 1H); ^{13}C NMR (DMSO, 500 MHz) δ 167.7, 152.6, 148.6(2), 145.2, 137.4(2), 133.5, 128.5, 126.9, 125.3, 124.4, 104.3, 102.1, 94.3, 76.9, 76.7, 70.4, 53.9; ^{31}P (DMSO- d_6 , 200 MHz) 20.3 (s, 1P); found by HRAPCI (negative ions) mass spec. 368.0179, calc. for $\text{C}_{14}\text{H}_{11}\text{O}_9\text{NP}$ 368.2164.

Crystal Structure of Pyridinium Narcistatin (3a).

X-Ray Crystal Structure Determination. Pyridinium narcistatin hydrate (3a): A thin plate ($\sim 0.07 \times 0.35 \times 0.54$ mm), grown from pyridine/water solution, was mounted on the tip of a glass fiber. Cell parameter measurements and data collection were performed at 123 K with a Bruker SMART 6000 diffractometer system using Cu $K\alpha$ radiation. A sphere of reciprocal space was covered using the multirun technique. SMART for Windows NT v5.605; BrukerAXS Inc.: Madison, WI, 2000. Thus, six sets of frames of data were collected with 0.396° steps in ω , and a last set of frames with 0.396° steps in ϕ , such that 91.7% coverage of all unique reflections to a resolution of 0.84Å was accomplished.

Crystal Data: $C_{14}H_{11}NO_9P \cdot C_5H_6N \cdot 1 \frac{1}{2} H_2O$ (hydrate), $M_r=475.34$, triclinic, P1, $a=7.4949(1)$, $b=8.0371(1)$, $c=16.9589(2)$ Å, $\alpha=85.248(1)$, $\beta = 83.243(1)$, $\gamma=79.383(1)^\circ$, $V=994.60(2)$ Å³, $Z=2$, $\rho_c=1.577$ Mg/m³, $\mu(\text{CuK}\alpha)=1.837$ mm⁻¹, $\lambda=1.54178$ Å, $F(000)=494$.

A total of 7587 reflections was collected, of which 4733 reflections were independent reflections ($R(\text{int}) = 0.0273$). Subsequent statistical analysis of the data set with the XPREP program indicated the spacegroup was P1. XPREP-The automatic space group determination program in the SHELXTL. (SHELXTL-NT Version 5.10; BrukerAXS Inc., Madison, WI, 1997: an integrated suite of programs for the determination of crystal structures from diffraction data. This package includes, among others, XPREP (an automatic space group determination program), SHELXS (a structure solution program via Patterson or direct methods), and SHELXL (structure refinement software)). Final cell constants were determined from the set of the 4564 observed ($>2\sigma(I)$) reflections which were used in structure solution and refinement. An absorption correction was applied to the data with SADABS. (Blessing, R., Acta Crystallogr. 1995, A51, 33-38.) Structure determination and refinement was readily accomplished with the direct-methods program SHELXTL. (SHELXTL-NT Version 5.10; Bruker AXS Inc.: Madison, WI, 1997.) An integrated suite of programs for the determination of crystal structures from diffraction data. This package includes, among others, XPREP (an automatic space group determination program), SHELXS (a structure solution program via Patterson or direct methods), and SHELXL (structure refinement software). All non-hydrogen atom coordinates were located in a routine run using default values for that program. The remaining H atom coordinates were calculated at optimum positions, except for water hydrogen atoms, which were located *via* difference maps. All non-hydrogen atoms were refined anisotropically in a full-matrix least-squares refinement procedure. The H atoms were included, their Uiso thermal parameters

fixed at either 1.2 or 1.5 (depending on atom type) the value of the Uiso of the atom to which they were attached and forced to ride that atom. The final standard residual R_1 value for **3a** was 0.0393 for observed data and 0.0403 for all data. The goodness-of-fit on F^2 was 1.053. The corresponding Sheldrick R values were wR_2 of 0.1074 and 0.1099, respectively. The final model used for pyridinium narcistatin **3a** is shown in Figure 1. In addition to the parent molecules (i.e., two narcistatin anions and two pyridinium cations) in the unit cell, three molecules of water solvate were also present. One of these water molecules was disordered over two sites, each of which were given 0.5 site occupancies. A final difference Fourier map showed minimal residual electron density; the largest difference peak and hole being +0.350 and -0.255 $e/\text{\AA}^3$, respectively. Final bond distances and angles were all within expected and acceptable limits.

Narcistatin (3b).

A solution of pyridinium narcistatin (**3a**, 0.05 g) in water (2 ml) was obtained by heating (water bath) at 60°C and allowing the solution to cool prior to passing through a column prepared from Dowex 50X8-200 cation exchange resin (hydrogen form). A suspension began to form in the column as the phosphoric acid (**3b**) formed. The column was eluted with water and phosphoric acid **3b** eluted as a milky white suspension. The combined fractions containing phosphoric acid **3b** were freeze dried to afford the product as a colorless solid, (36 mg, 86%); m.p. 175°C (dec.); ^1H NMR (DMSO- d_6 , 300 MHz), δ 13.65 (s, 1H), 9.02 (s, 1H), 7.06 (s, 1H), 6.48 (s, 1H), 6.17 (d, $J_{ab} = 10.2$ Hz, 1H), 6.06 (m, 2H), 4.46-4.30 (m, 3H), 4.18 (m, 1H); calc for $\text{C}_{14}\text{H}_{13}\text{NO}_9\text{P}$ 370.0328; found by HR (APCI) $[\text{M}+\text{H}]^+$ 370.0361.

General Procedure for Preparation of Narcistatin Prodrugs 3c-f.

Pyridinium narcistatin (**3a**, 50 mg) was dissolved in water (35 ml) and the solution passed through a column (1 x 20 cm) of Dowex 50W-X2 bearing the respective cation. The u.v. active fractions were combined and freeze dried to give the corresponding narcistatin salt as a colorless solid unless otherwise recorded. The solubility of each in water (mg/ml) now follows: **3c**, >50 mg; **3d**, 60 mg; **3e**, 11 mg; **3f**, <13 mg.

Lithium Narcistatin (3c).

Yield, 65 mg, 77%; m.p. 220°C (dec); ¹H NMR (DMSO-d₆, 500 MHz) δ 13.79 (s, 1H), 8.71 (s, 1H), 7.07 (s, 1H), 6.49 (s, 1H), 6.13 (m, 2H), 4.36 (m, 2H), 4.04 (m, 1H), 3.93 (m, 1H); ¹³C NMR (DMSO-d₆, 300 MHz), 167.6, 152.5, 145.2, 133.3, 129.1, 127.3, 125.6, 104.3, 101.9, 94.2, 75.2, 74.6, 70.4, 53.8.

Sodium Narcistatin (3d). (Procedure A).

Colorless solid, 38 mg, 87%); [α]²⁵_D = -6.33 (c 0.3, DMSO); m.p. 275°C; ¹H NMR (DMSO-d₆, 500 MHz) δ 13.72 (s, 1H) 8.63 (s, 1H), 6.99 (s, 1H), 6.41 (s, 1H), 6.05 (m, 2H), 5.77 (bs, 1H), 4.26 (m, 2H), 3.4 (m, 1H), 3.83 (m, 1H); ¹³C NMR (DMSO-d₆, 500 MHz), 167.6, 152.5, 145.2, 133.3, 129.1, 127.3, 125.5, 104.3, 101.9, 94.2, 75.2, 74.5, 70.4, 53.9; ³¹P (DMSO-d₆, 200 MHz) 16.98.

Sodium Narcistatin (3d). Procedure B.

Narciclasine 1 (0.113 g, 0.368 mmol) was added to pyridine (4ml) and the solution heated to 80°C. Next, tetrabutylammonium dihydrogen phosphate (0.075 g, 0.22 mmol, 0.6 equiv.) and dicyclohexylcarbodiimide (0.4 g, 1.93 mmol, 5 equiv.) were added. The reaction mixture was stirred under argon at 80°C for 24 hours. Tetrabutylammonium dihydrogen phosphate (0.185 g) was added followed by DCCI (0.4 g) and the reaction stirred for a further 72 hours. ¹H NMR (DMSO-d₆) of the crude reaction mixture showed complete conversion to product. The reaction was cooled and filtered. Water (100 ml) was added to the mother

liquor, which was then filtered to remove any precipitated DCU. The aqueous solution was then concentrated to minimum volume. The solution was then eluted on an ion exchange column of Dowex 50WX8-200 (sodium form) and the UV active fractions were combined and freeze dried to afford the product as a white solid (0.113 mg, 88%). Comparison of the ^1H NMR of this product in DMSO- d_6 with the narcistatin sodium salt 3d prepared from the pyridinium narcistatin 3a by the method outlined above showed them to be identical. This method is more practical and dramatically improves the yield of narcistatin from narciclasine.

Potassium Narcistatin (3e)

Off-white solid, 59 mg, 80%, m.p. 250°C, ^1H NMR (DMSO- d_6 , 300 MHz) δ 13.74 (s, 1H), 8.65 (s, 1H), 6.98 (s, 1H), 6.40 (s, 1H), 6.04 (d, $J_{ab} = 2.4$ Hz, 2H), 5.74 (bs, 1H), 4.25 (m, 2H), 3.9 (m, 1H), 3.78 (m, 1H).

Cesium Narcistatin (3f)

Off white solid, 51 mg, 91%, m.p. 245°C; ^1H NMR (DMSO- d_6 , 300 MHz) δ 13.74 (s, 1H), 8.65 (s, 1H), 6.98 (s, 1H), 6.40 (s, 1H), 6.04 (m, 2H), 5.74 (bs, 1H), 4.25 (m, 2H), 3.92 (m, 1H), 3.79 (m, 1H).

An alternative method was also developed to isolate yield narcistatin sodium salt 3d. Narciclasine, tetrabutylammonium dihydrogen phosphate, DCCI and pyridinium *p*-toluene sulfonate were allowed to react at room temperature for 2 days. The reaction was monitored by t.l.c. using the solvent system 4:3:2:1 butanol-methanol-water-concentrated aqueous ammonia. Two major fluorescent spots were evident, narciclasine at R_f 0.65 and product at a higher R_f 0.69. Even after 4 days of stirring, the reaction was incomplete. The reaction mixture was added to water, the DCU collected, the mother liquor was evaporated to half its volume, and 2N aqueous ammonia was added at regular intervals to maintain a pH of 8-9. The solution was passed through a column (15 x 15 cm) of Dowex 50 (pyridinium form) in

order to remove the unreacted narciclasine. Narciclasine remained bound to the resin while the charged phosphate passed through unchanged. The column was then washed with methanol and the unreacted narciclasine was recovered. The cyclic phosphate was separated from contaminating inorganic phosphate by anion exchange chromatography using DEAE-Sephadex and gradient elution with aqueous triethyl ammonium bicarbonate. The triethyl ammonium salt was converted to the sodium salt by passage through a Dowex 50 column (Na^+ form). A ^{31}P -NMR confirmed the presence of a phosphate group. The yield from this reaction was 43%. Comparison of the ^1H NMR of this product in D_2O with the narcistatin sodium salt **3d** prepared from the pyridinium narcistatin **3a** by the method outlined above showed them to be identical. However, this method proved less practical and did not significantly improve the yield.

General Procedure for Preparation of Narcistatin Divalent Cation Salts 3g-j.

The experiment leading to magnesium salt **3g** provides the general method and relative quantities of reactants and solvents. In each case, the respective metal acetate was employed.

Magnesium Narcistatin (3g)

To a mixture of phosphoric acid (**3b**, 50 mg, 0.135 mmol) and methanol-water (3:2) was added a solution of magnesium acetate (15 mg, 0.0675 mmol, 0.5 equiv) in water (1 ml). The mixture became opaque immediately upon addition of the metal acetate and was stirred for 3 days while further precipitation occurred. The solution was concentrated to a white residue and water-methanol was added (1.4 ml). The precipitate was collected and dried; grey solid, m.p. 210°C dec. very insoluble in water, soluble in DMSO; ^1H -NMR ($\text{DMSO}-d_6$, 300 MHz) δ 13.69 (s, 1H), 8.73 (s, 1H), 6.99 (s, 1H), 6.43 (s, 1H), 6.14 (m, 1H), 6.05 (s, 2H), 5.82 (bs, 1H), 4.41 - 4.31 (m, 2H), 4.03 - 3.95 (m, 2H). Each of the divalent cation salts

proved to be only sparingly soluble in water.

Calcium Narcistatin (3h)

Grey solid; 30 mg, m.p. 195°C (dec). ¹H NMR (DMSO-d₆, 300 MHz), δ 13.68 (s, 1H), 8.69 (s, 1H), 7.0 (s, 1H), 6.43 (s, 1H), 6.14 (d, J = 12.9 Hz, 1H), 6.05 (m, 2H), 4.29 (m, 2H), 4.02 (m, 1H), 3.94 (m, 1H).

Zinc Narcistatin (3i)

Yield of grey solid, 23 mg, m.p. 200°C (dec). ¹H NMR (DMSO-d₆, 300 MHz), δ 13.64 (s, 1H), 8.81 (s, 1H), 6.92 (s, 1H), 6.38 (s, 1H), 6.16 (m, 1H), 6.03 (s, 2H), 5.94 (bs, 1H), 4.31 (m, 2H), 4.20-4.17 (m, 1H), 4.07 (m, 1H).

Manganese Narcistatin (3j)

For this experiment, 41 mg of narcistatin (3b) was treated with manganese acetate (16 mg, 0.065 mmol, 0.5 equiv) in water (1 ml) to afford 35 mg of grey solid, m.p. 165°C (dec); ¹H NMR (DMSO-d₆, 300 MHz). The salt, while quite soluble in DMSO-d₆, did not give a useful spectrum.

General procedure for obtaining ammonium salts 3k-o.

Phosphoric acid 3b (0.25 g) was dissolved in methanol-dichloromethane-water (3:1:1) (10 ml). A 2 ml aliquot of the phosphoric acid solution was added to each of the five flasks containing 1.2 equivalents of the respective amine and the reaction mixture stirred for 24 hr at rt. A precipitate separated from the reaction mixture with the quinine and imidazole examples. The solvent was concentrated and the residues reprecipitated from water-methanol to yield each of the ammonium salts 3k-o).

Quinidinium Narcistatin (3k).

Cream-colored solid; 34 mg, m.p. 205°C (dec, 220°C melts); ¹H NMR (DMSO-d₆, 300 MHz), δ 13.71 (s, 1H), 8.68 (bs, 2H), 7.90 (d, J = 8.4 Hz, 1H), 7.52 (s, 1H), 7.37 - 7.40

(m, 3H), 6.99 (s, 1H), 6.4 (s, 1H), 6.13 - 6.01 (m, 3H), 5.10 (m, 4H), 4.25 (m, 2H), 3.92 (m, 5H), 3.6 - 3.2 (m, 6H), 2.42 (m, 1H), 2.2 - 2.12 (m, 1H), 1.91 - 1.84 (m, 1H), 1.60 (m, 2H), 1.47 - 1.38 (m, 1H).

Quininium Narcistatin (3l).

Cream-colored solid; 55 mg, m.p. 195°C; ¹H NMR (DMSO-d₆, 300 MHz), δ 13.72 (s, 1H), 8.70 (bs, 2H), 7.93 (d, J = 8.4 Hz, 1H), 7.57 (bs, 1H), 7.45 - 7.39 (m, 3H), 6.99 (s, 1H), 6.41 (s, 1H), 6.05 (m, 3H), 5.80 - 5.73 (m, 2H), 5.07 - 4.93 (m, 2H), 4.25 (bs, 2H), 4.03 - 3.85 (m, 5H), 3.38 (m, 6H), 1.91 (m, 4H), 1.71 (m, 1H), 1.47 (m, 1H).

Imidazolium Narcistatin (3m).

Off-white solid, 39 mg, m.p. 210°C; ¹H NMR (DMSO-d₆ 300 MHz), δ 13.73 (s, 1H), 13.4 (s, 1H), 8.71 (s, 1H), 8.06 (bs, 1H), 7.21 (bm, 2H), 6.98 (s, 1H), 6.41 (s, 1H), 6.11 (bs, 1H), 6.04 (m, 2H), 4.25 (m, 2H), 3.99 (m, 1H), 3.84 (m, 1H).

Morpholinium Narcistatin (3n).

Off-white solid, 20 mg, m.p. 230°C; ¹H NMR (DMSO-d₆ 300 MHz), δ 13.73 (s, 1H), 8.68 (s, 1H), 6.99 (s, 1H), 6.41 (s, 1H), 6.04 (d, J = 2.7 Hz, 2H), 5.76 (bs, 1H), 4.25 (bm, 2H), 3.97 (m, 1H), 3.92 - 3.71 (m, 5H), 3.03 (m, 4H), 1.22 (s, 1H).

Piperazinium Narcistatin (3o).

Off-white solid, 21 mg, m.p. 270°C; ¹H NMR (DMSO-d₆ 300 MHz), δ 13.74 (s, 1H), 8.66 (s, 1H), 6.98 (s, 1H), 6.40 (s, 1H), 6.04 (d, J = 1.8 Hz, 2H), 5.74 (bs, 1H), 4.24 (bm, 2H), 3.93 (m, 1H), 3.81 (m, 1H), 3.14 (s, 2H), 2.83 (s, 9H).

ADMINISTRATION

Dosages

The dosage of the presently disclosed compounds to be administered to humans and

other animals requiring treatment will depend upon numerous factors, including the identity of the neoplastic disease; the type of host involved, including its age, health and weight; the kind of concurrent treatment, if any; the frequency of treatment and therapeutic ratio. Hereinafter are described various possible dosages and methods of administration, with the understanding that the following are intended to be illustrative only, and that the actual dosages to be administered, and methods of administration or delivery may vary therefrom. The proper dosages and administration forms and methods may be determined by one of skill in the art.

Illustratively, dosage levels of the administered active ingredients are: intravenous, 0.1 to about 200 mg/kg; intramuscular, 1 to about 500 mg/kg; orally, 5 to about 1000 mg/kg; intranasal instillation, 5 to about 1000 mg/kg; and aerosol, 5 to about 1000 mg/kg of host body weight.

Expressed in terms of concentration, an active ingredient can be present in the compositions of the present invention for localized use about the cutis, intranasally, pharyngolaryngeally, bronchially, intravaginally, rectally, or ocularly in concentration of from about 0.01 to about 50% w/w of the composition; preferably about 1 to about 20% w/w of the composition; and for parenteral use in a concentration of from about 0.05 to about 50% w/v of the composition and preferably from about 5 to about 20% w/v.

The compositions of the present invention are preferably presented for administration to humans and animals in unit dosage forms, such as tablets, capsules, pills, powders, granules, suppositories, sterile parenteral solutions or suspensions, sterile non-parenteral solutions of suspensions, and oral solutions or suspensions and the like, containing suitable quantities of an active ingredient.

For oral administration either solid or fluid unit dosage forms can be prepared.

Powders are prepared quite simply by comminuting the active ingredient to a suitably fine size and mixing with a similarly comminuted diluent. The diluent can be an edible carbohydrate material such as lactose or starch. Advantageously, a sweetening agent or sugar is present as well as a flavoring oil.

Capsules are produced by preparing a powder mixture as hereinbefore described and filling into formed gelatin sheaths. Advantageously, as an adjuvant to the filling operation, a lubricant such as talc, magnesium stearate, calcium stearate and the like is added to the powder mixture before the filling operation.

Soft gelatin capsules are prepared by machine encapsulation of a slurry of active ingredients with an acceptable vegetable oil, light liquid petrolatum or other inert oil or triglyceride.

Tablets are made by preparing a powder mixture, granulating or slugging, adding a lubricant and pressing into tablets. The powder mixture is prepared by mixing an active ingredient, suitably comminuted, with a diluent or base such as starch, lactose, kaolin, dicalcium phosphate and the like. The powder mixture can be granulated by wetting with a binder such as corn syrup, gelatin solution, methylcellulose solution or acacia mucilage and forcing through a screen. As an alternative to granulating, the powder mixture can be slugged, i.e., run through the tablet machine and the resulting imperfectly formed tablets broken into pieces (slugs). The slugs can be lubricated to prevent sticking to the tablet-forming dies by means of the addition of stearic acid, a stearic salt, talc or mineral oil. The lubricated mixture is then compressed into tablets.

Advantageously, the tablet can be provided with a protective coating consisting of a sealing coat or enteric coat of shellac, a coating of sugar and methylcellulose and polish coating of carnauba wax.

Fluid unit dosage forms for oral administration such as in syrups, elixirs and suspensions can be prepared wherein each teaspoonful of composition contains a predetermined amount of an active ingredient for administration.

The water-soluble forms can be dissolved in an aqueous vehicle together with sugar, flavoring agents and preservatives to form a syrup. An elixir is prepared by using a hydroalcoholic vehicle with suitable sweeteners together with a flavoring agent. Suspensions can be prepared of the insoluble forms with a suitable vehicle with the aid of a suspending agent such as acacia, tragacanth, methylcellulose and the like.

For parenteral administration, fluid unit dosage forms are prepared utilizing an active ingredient and a sterile vehicle, water being preferred. The active ingredient, depending on the form and concentration used, can be either suspended or dissolved in the vehicle. In preparing solutions the water-soluble active ingredient can be dissolved in water for injection and filter sterilized before filling into a suitable vial or ampule and sealing. Advantageously, adjuvants such as a local anesthetic, preservative and buffering agents can be dissolved in the vehicle. Parenteral suspensions are prepared in substantially the same manner except that an active ingredient is suspended in the vehicle instead of being dissolved and sterilization cannot be accomplished by filtration. The active ingredient can be sterilized by exposure to ethylene oxide before suspending in the sterile vehicle. Advantageously, a surfactant or wetting agent is included in the composition to facilitate uniform distribution of the active ingredient.

In addition to oral and parenteral administration, the rectal and vaginal routes can be utilized. An active ingredient can be administered by means of a suppository. A vehicle which has a melting point at about body temperature or one that is readily soluble can be utilized. For example, cocoa butter and various polyethylene glycols (Carbowaxes) can serve

as the vehicle.

For intranasal installation, a fluid unit dosage form is prepared utilizing an active ingredient and a suitable pharmaceutical vehicle, preferably purified (P.F.) water, a dry powder, can be formulated when insolation is the administration of choice.

For use as aerosols, the active ingredients can be packaged in a pressurized aerosol container together with a gaseous or liquefied propellant, for example, dichlorodifluoromethane, carbon dioxide, nitrogen, propane, and the like, with the usual adjuvants such as cosolvents and wetting agents, as may be necessary or desirable.

The term "unit dosage form" as used in the specification and claims refers to physically discrete units suitable as unitary dosages for human and animal subjects, each unit containing a predetermined quantity of active material calculated to produce the desired therapeutic effect in association with the required pharmaceutical diluent, carrier or vehicle. The specifications for the novel unit dosage forms of this invention are dictated by and are directly dependent on (a) the unique characteristics of the active material and the particular therapeutic effect to be achieved, and (b) the limitation inherent in the art of compounding such an active material for therapeutic use in humans, as disclosed in this specification, these being features of the present invention. Examples of suitable unit dosage forms in accord with this invention are tablets, capsules, troches, suppositories, powder packets, wafers, cachets, teaspoonfuls, tablespoonfuls, dropperfuls, ampules, vials, segregated multiples of any of the foregoing, and other forms as herein described.

The active ingredients to be employed as antineoplastic agents can be easily prepared in such unit dosage form with the employment of pharmaceutical materials which themselves are available in the art and can be prepared by established procedures. The following preparations are illustrative of the preparation of the unit dosage forms of the present

invention, and not as a limitation thereof. Several dosage forms were prepared embodying the present invention. They are shown in the following examples in which the notation "active ingredient" signifies one or more of the compounds described herein.

COMPOSITION "A"

Hard-Gelatin Capsules

One thousand two-piece hard gelatin capsules for oral use, each capsule containing 200 mg of an active ingredient are prepared from the following types and amounts of ingredients:

Active ingredient, micronized	200 g
Corn Starch	20 g
Talc	20 g
Magnesium stearate	2 g

The active ingredient, finely divided by means of an air micronizer, is added to the other finely powdered ingredients, mixed thoroughly and then encapsulated in the usual manner.

The foregoing capsules are useful for treating a neoplastic disease by the oral administration of one or two capsules one to four times a day.

Using the procedure above, capsules are similarly prepared containing an active ingredient in 50, 250 and 500 mg amounts by substituting 50 g, 250 g and 500 g of an active ingredient for the 200 g used above.

COMPOSITION "B"

Soft Gelatin Capsules

One-piece soft gelatin capsules for oral use, each containing 200 mg of an active ingredient, finely divided by means of an air micronizer, are prepared by first suspending the

compound in 0.5 ml of corn oil to render the material capsulatable and then encapsulating in the above manner.

The foregoing capsules are useful for treating a neoplastic disease by the oral administration of one or two capsules one to four times a day.

COMPOSITION "C"

Tablets

One thousand tablets, each containing 200 mg of an active ingredient, are prepared from the following types and amounts of ingredients:

Active ingredient, micronized	200 g
Lactose	300 g
Corn starch	50 g
Magnesium stearate	4 g
Light liquid petrolatum	5 g

The active ingredient, finely divided by means of an air micronizer, is added to the other ingredients and then thoroughly mixed and slugged. The slugs are broken down by forcing them through a Number Sixteen screen. The resulting granules are then compressed into tablets, each tablet containing 200 mg of the active ingredient.

The foregoing tablets are useful for treating a neoplastic disease by the oral administration of one or two tablets one to four times a day.

Using the procedure above, tablets are similarly prepared containing an active ingredient in 250 mg and 100 mg amounts by substituting 250 g and 100 g of an active ingredient for the 200 g used above.

COMPOSITION "D"

Oral Suspension

One liter of an aqueous suspension for oral use, containing in each teaspoonful (5 ml) dose, 50 mg of an active ingredient, is prepared from the following types and amounts of ingredients:

Active ingredient, micronized	10 g
Citric acid	2 g
Benzoic acid	1 g
Sucrose	790 g
Tragacanth	5 g
Lemon Oil	2 g
Deionized water, q.s.	1000 ml

The citric acid, benzoic acid, sucrose, tragacanth and lemon oil are dispersed in sufficient water to make 850 ml of suspension. The active ingredient, finely divided by means of an air micronizer, is stirred into the syrup unit uniformly distributed. Sufficient water is added to make 1000 ml.

The composition so prepared is useful for treating a neoplastic disease at a dose of 1 teaspoonful (15 ml) three times a day.

COMPOSITION "E"

Parenteral Product

A sterile aqueous suspension for parenteral injection, containing 30 mg of an active ingredient in each milliliter for treating a neoplastic disease, is prepared from the following types and amounts of ingredients:

Active ingredient, micronized	30 g
POLYSORBATE 80	5 g
Methylparaben	2.5 g

Propylparaben	0.17 g
Water for injection, q. s.	1000 ml.

All the ingredients, except the active ingredient, are dissolved in the water and the solution sterilized by filtration. To the sterile solution is added the sterilized active ingredient, finely divided by means of an air micronizer, and the final suspension is filled into sterile vials and the vials sealed.

The composition so prepared is useful for treating a neoplastic disease at a dose of 1 milliliter (1ml) three times a day.

COMPOSITION "F"

Suppository, Rectal and Vaginal

One thousand suppositories, each weighing 2.5 g and containing 200 mg of an active ingredient are prepared from the following types and amounts of ingredients:

Active ingredient, micronized	15 g
Propylene glycol	150 g
Polyethylene glycol #4000, q.s.	2,500 g

The active ingredient is finely divided by means of an air micronizer and added to the propylene glycol and the mixture passed through a colloid mill until uniformly dispersed. The polyethylene glycol is melted and the propylene glycol dispersion is added slowly with stirring. The suspension is poured into unchilled molds at 40 °C. The composition is allowed to cool and solidify and then removed from the mold and each suppository foil wrapped.

The foregoing suppositories are inserted rectally or vaginally for treating a neoplastic disease.

COMPOSITION "G"

Intranasal Suspension

One liter of a sterile aqueous suspension for intranasal instillation, containing 20 mg of an active ingredient in each milliliter, is prepared from the following types and amounts of ingredients:

Active ingredient, micronized	15 g
POLYSORBATE 80	5 g
Methylparaben	2.5 g
Propylparaben	0.17 g
Deionized water, q.s.	1000 ml.

All the ingredients, except the active ingredient, are dissolved in the water and the solution sterilized by filtration. To the sterile solution is added the sterilized active ingredient, finely divided by means of an air micronizer, and the final suspension is aseptically filled into sterile containers.

The composition so prepared is useful for treating a neoplastic disease, by intranasal instillation of 0.2 to 0.5 ml given one to four times per day.

An active ingredient can also be present in the undiluted pure form for use locally about the cutis, intranasally, pharyngolaryngeally, bronchially, or orally.

COMPOSITION "H"

Powder

Five grams of an active ingredient in bulk form is finely divided by means of an air micronizer. The micronized powder is placed in a shaker-type container.

The foregoing composition is useful for treating a neoplastic disease, at localized sites by applying a powder one to four times per day.

COMPOSITION "T"

Oral Powder

One hundred grams of an active ingredient in bulk form is finely divided by means of an air micronizer. The micronized powder is divided into individual doses of 200 mg and packaged.

The foregoing powders are useful for treating a neoplastic disease, by the oral administration of one or two powders suspended in a glass of water, one to four times per day.

COMPOSITION "J"

Insulation

One hundred grams of an active ingredient in bulk form is finely divided by means of an air micronizer.

The foregoing composition is useful for treating a neoplastic disease, by the inhalation of 300 mg one to four times a day.

It is of course understood that such modifications, alterations and adaptations as will readily occur to the artisan confronted with this disclosure are intended within the spirit of the present invention.

Table 1. Solubilities, Human Cancer Cell Line and Murine P-388 Lymphocytic Inhibitory Activities of Cyclic Phosphates 3-16.

Compound	Solubilities ^a (mg/ml)	ED ₅₀ (μg/ml)	GI ₅₀ (μg/ml)					
			Pancreas-a BXPC-3	Breast MCF-7	CNS SF 268	Lung-NSC NCI-H460	Colon KM20L2	Prostate DU-145
3a	7	1.91 x 10 ⁻¹	2.2 x 10 ⁻¹	2.7 x 10 ⁻¹	1.5 x 10 ⁻¹	2.7 x 10 ⁻¹	3.4 x 10 ⁻¹	1.7 x 10 ⁻¹
3b	4	2.75 x 10 ⁻¹	3.3 x 10 ⁻¹	3.5 x 10 ⁻¹	2.2 x 10 ⁻¹	4.7 x 10 ⁻¹	5.3 x 10 ⁻¹	1.6 x 10 ⁻¹
3c	>50	1.21 x 10 ⁻¹	2.5 x 10 ⁻¹	3.1 x 10 ⁻¹	1.7 x 10 ⁻¹	3.0 x 10 ⁻¹	2.6 x 10 ⁻¹	1.3 x 10 ⁻¹
3d	60	2.55 x 10 ⁻¹	3.2 x 10 ⁻¹	5.6 x 10 ⁻¹	2.3 x 10 ⁻¹	>1	4.5 x 10 ⁻¹	1.2 x 10 ⁻¹
3e	11	2.42 x 10 ⁻¹	3.6 x 10 ⁻¹	4.0 x 10 ⁻¹	1.9 x 10 ⁻¹	6.7 x 10 ⁻¹	5.6 x 10 ⁻¹	2.6 x 10 ⁻¹
3f	<13	1.83 x 10 ⁻¹	4.1 x 10 ⁻¹	6.2 x 10 ⁻¹	3.3 x 10 ⁻¹	>1	6.6 x 10 ⁻¹	1.3 x 10 ⁻¹
3g	<1.5	1.70 x 10 ⁻¹	1.9 x 10 ⁻¹	2.5 x 10 ⁻¹	1.4 x 10 ⁻¹	2.9 x 10 ⁻¹	3.1 x 10 ⁻¹	1.0 x 10 ⁻¹
3h	<1	2.23 x 10 ⁻²	4.5 x 10 ⁻²	5.9 x 10 ⁻²	3.1 x 10 ⁻²	1.2 x 10 ⁻¹	5.9 x 10 ⁻²	9.3 x 10 ⁻³
3i	1.7	2.87 x 10 ⁻²	6.9 x 10 ⁻²	1.4 x 10 ⁻¹	5.3 x 10 ⁻²	2.1 x 10 ⁻¹	1.6 x 10 ⁻¹	1.6 x 10 ⁻²
3j	<3	4.27 x 10 ⁻²	4.9 x 10 ⁻²	7.0 x 10 ⁻²	4.0 x 10 ⁻²	1.5 x 10 ⁻¹	1.3 x 10 ⁻¹	3.4 x 10 ⁻²
3k	<1	2.71 x 10 ⁻¹	3.1 x 10 ⁻¹	5.0 x 10 ⁻¹	2.5 x 10 ⁻¹	7.7 x 10 ⁻¹	5.8 x 10 ⁻¹	2.2 x 10 ⁻¹
3l	<1	3.42 x 10 ⁻²	5.1 x 10 ⁻²	1.2 x 10 ⁻¹	4.5 x 10 ⁻²	1.7 x 10 ⁻¹	1.2 x 10 ⁻¹	1.3 x 10 ⁻²
3m	5.8	2.40 x 10 ⁻¹	4.5 x 10 ⁻¹	9.0 x 10 ⁻¹	3.8 x 10 ⁻¹	>1	>1	4.4 x 10 ⁻¹
3n	>13	2.32 x 10 ⁻¹	2.5 x 10 ⁻¹	4.8 x 10 ⁻¹	2.4 x 10 ⁻¹	>1	5.4 x 10 ⁻¹	1.4 x 10 ⁻¹
3o	1.9	3.78 x 10 ⁻²	1.0 x 10 ⁻¹	1.7 x 10 ⁻¹	9.9 x 10 ⁻²	2.4 x 10 ⁻¹	2.2 x 10 ⁻¹	3.2 x 10 ⁻²

^aSolubility values were obtained using 1 ml distilled water at 25°C.